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Black and green tea (*Camellia sinensis* L.) extracts as natural antioxidants in uncured pork sausages

Barana C. Jayawardana[1] | Viraji Bandara Warnasooriya[1] | G. H. Thotawattage[2] | V. A. K. I. Dharmasena[1] | Ruvini Liyanage[3]

[1]Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

[2]Biochemistry Division, Tea Research Institute, Thalawakelle, Sri Lanka

[3]National Institute of Fundamental Studies, Kandy, Sri Lanka

Correspondence
Barana C. Jayawardana, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.
Emails: baranaj@pdn.ac.lk; baranaj2000@yahoo.com

Abstract

The present study evaluated the antioxidant effect of green and black tea (*Camellia sinensis* L.) extracts in uncured pork sausages. The total polyphenol content in the green tea extract (GTE) was significantly higher ($p < 0.05$) than the black tea extract (BTE). DPPH assay showed significantly higher ($p < 0.05$) antioxidant activity in GTE compared to BTE. However, TBARS values of uncured pork sausages significantly reduced ($p < 0.05$) for all levels of concentrations of BTE (0.05%, 0.10%, 020%, and 0.30%) and GTE (0.05%, 0.10, 0.20%, and 0.30%) during the 5 days storage period. The reduction of TBARS values for the BTE 0.05% treated sausage sample was not, however, significantly different ($p > 0.05$) to the BHT 0.10% treated sausage sample on fifth day of the storage period. The sensory evaluation of pork sausages incorporated with a BTE of 0.05% and 0.30%, GTE of 0.05% and the control were not significantly differences ($p < 0.05$) in color, odor, texture, juiciness, taste, or overall acceptability.

Practical applications

In the present study, we evaluated the antioxidant effect of green and black tea (*Camellia sinensis L.*) extracts in uncured pork sausages. Adding of black tea extract 0.05%, 0.30%, and green tea extract 0.05% can reduce the TBARS value in uncured pork sausages without altering color, odor, texture, juiciness, or overall acceptability. Therefore, 0.05%, 0.30% black tea extract and 0.05% green tea extracts can be considered as potential antioxidants in uncured pork sausages.

1 | INTRODUCTION

Lipid oxidation and auto-oxidation are major causes of deterioration and reduced shelf life of the minced meat products (Lorenzo, Munekata, Gómez, et al., 2018; Lorenzo, Munekata, Sant'Ana, et al., 2018) and can be accelerated by several factors such as increased levels of unsaturated fatty acids, polyunsaturated fatty acids, oxygen, heat, UV light, metal ions, meat/heme pigments, and oxidative enzymes (Morrissey, Sheehy, Galvin, Kerry, & Buckley, 1998). Due to the high fat content, the comminuted nature of the raw materials and the lack of thermal processing, such products are prone to spoilage by lipid oxidation and microbial contamination (Georgantelis, Ambrosiadis, Katikou, Blekas, & Georgakis, 2007). A variety of reactive and toxic compounds are produced during these deteriorative changes and they can adversely effect on the health and wellbeing of humans (Morrissey et al., 1998). Thus, it is essential to prevent these deteriorative changes from occurring in the fats and oils (Franco et al., 2018; Jayasena & Jo, 2014).

The use of antioxidants to combat deterioration is not new today. Various synthetic antioxidants such as butylatedhydroxytoluene

(BHT), butylatedhydroxyanisole (BHA), and propyl gallate (PG) are used to retard lipid oxidation and extend shelf life in meat products (Christinawaty & Damayanti, 2015). Consumers prefer natural antioxidants to synthetic antioxidants, mainly for emotional reasons (Lorenzo, Pateiro, et al., 2018). The safety limits of natural antioxidants are mostly not known, but they are much safer than synthetic antioxidants (Pokorný, 2007). Some studies revealed that due to some concerns about the associated risk of cancer, these synthetic compounds are banned in several countries since years before (Wanasundara & Shahidi, 1998). There are lots of reports on plant-based natural antioxidants. Many herbs, spices, and their extracts have been reported as having high antioxidant capacity (Jayawardana et al., 2011; Jayawardana, Liyanage, Lalantha, Iddamalgoda, & Weththasinghe, 2015; Pateiro et al.., 2018; Shah, Bosco, & Mir, 2014). Among them rosemary (*Rosmarinus officinalis* L.), pomegranate (*Punica granatum*), sage (*Salvia officinalis* L.), drumstick (*Moringa Oleifera*), adzuki bean (*Vigna angularis*), garlic (*Allium sativum*), and green tea (Camellia sinensis) antioxidant effects has been studied extensively in related to meat products (Bozkurt, 2006; Georgantelis et al., 2007; Martinez, Cilla, Beltrán, & Roncalés, 2006; Jayasena & Jo, 2014; Jayawardana et al., 2011; Jayawardna et al., 2015; Kanatt, Chander & Sharma, 2010).

From almost 50 centuries, people have been consuming brewed tea from the leaves of the *Camellia sinensis* plant. Tea is the most popular beverage after water, enjoyed by many people across the globe and which is receiving lot of interest due to the many beneficial health effects associated with its regular consumption (Khan & Mukhtar, 2007). The consumption of tea has been associated with reduced risk of cardiovascular disease and certain types of cancer, inflammatory bowel, liver and neurodegenerative diseases, diabetes, and even weight loss (Lorenzo & Munekata, 2016). Usage of irradiated, freeze-dried green tea extract powder for producing functionally improved meat products was observed by Jo, Son, Son, and Byun (2003) through functional properties of raw and cooked pork patties during storage at 4°C. Paterio, Lorenzo, Amado, and Franco (2014) showed green tea extracts reduce the TBARS value increase in refrigerated stored pig pate. However, Sano et al. (1995) has studied that black tea has a higher inhibition potential than green tea. Moreover, Cao, Sofic, and Prior (1996) has shown that black tea has highest antioxidant capacity than green tea, garlic and other "teas" from other plants. Wambu, Fu, & Ho, 2017 have revealed that lot of researchers & institutions involved in tea-related research over the last decade and it indicates that there is a potential for incorporate Sri Lankan black and green tea to the food industry and medicinal purposes.

However, according to our knowledge no studies have been conducted to investigate the possibilities of incorporating black tea extracts as a natural antioxidant in processed meat products. Furthermore, although research has explored how black or green tea extracts may affect meat products in separate studies, there have been few attempts so far to compare the effects of black and green tea extracts in a single study. Thus, in the present study we evaluate the oxidative ability of green and black tea extracts and determine the feasibility of using black and green tea extracts in uncured pork sausages.

2 | MATERIALS & METHODS

2.1 | Materials

Freeze-dried tea extracts were prepared using black tea (Broken Orange Pekoe grade (BOP), St. Coombs estate, Thalawakelle, Sri Lanka), and Green tea (OPA II grade, Radella estate, Radella, Sri Lanka) brew according to international organization for standardization specification and those prepared powder form extracts were kept in the refrigeration temperature (4°C) till further use. Boneless pork (leg pork) was bought from the Livestock Field Station at Mawela, University of Peradeniya and stored at freezer condition (−18°C) until the experiment start. All other sausage ingredients were purchase from a local supermarket, Kandy, Sri Lanka. Methanol/water extraction mixture, 70% methanol (volume fraction), Folin–Ciocalteu phenol reagents, Sodium carbonate solution 7.5% (mass concentration), Gallic acid stock standard solution, Iso Butyl Methyl Ketone (IBMK), $NaHCO_3$, Oxalic acid, Trolox, 1,1-Diphenyl 1-2-picryl-hydrazyl 90% (DPPH) were supplied by Analytical Instruments Pvt. Ltd, Sri Lanka.

2.2 | Preparation of freeze-dried powdered tea extracts

Tea leaves and boiling water put in to beaker in 1:10 ratio and allowed to brew 5 min and filtered with linen cloth. Filtered extracts were evaporated in Rotavapor™ (R-250EX Buchi Labortechnik, Switzerland) at 50–80°C and 30°C for black and green tea, respectively. When the content reduced to half of its initial amount, it was removed from Rotavapor™ and allowed to reach room temperature. Then extracts were freeze-dried using a freeze-drying system (LABCONC corp., Missouri).

2.3 | Analysis of tea extracts

2.3.1 | Determination of moisture

Moisture content in initial samples of black tea and green tea were analyzed from ISO 1572.

2.3.2 | Determination of total polyphenol

The leaf tea samples were grinded in accordance with ISO 14502-1 and hot methanol/water extraction of both tea samples before and after extraction were prepared. Total polyphenols in both tea samples before extraction and after extraction were analyzed from colorimetric method using Folin–Ciocalteu reagent in ISO 14502-1:2005(E). Hot water extracts of tea samples were prepared and antioxidant activity was determined from DPPH assay according to Krings and Berger (2001). Trolox calibration curve

was drawn using inhibition percentage and Trolox concentration (ppm). The antioxidant activity in terms of Trolox equivalents was calculated.

2.4 | Preparation of meat model

Deep-frozen pork meat was thawed at refrigerated condition (4°C) overnight and mincing was done by meat mincer (H.L. TJ12-B, Guangdong Henglian Food Machinery, China). Minced meat sample chopped using emulsion-type bowl meat chopper (HANAKI Manufactories, Co. Ltd, Japan) with other ingredients as lean, lard, ice flacks, salt, and antioxidant for 10 min. Then the meat batter was transferred to semi-automated stuffer (F.DICK GmbH, Germany) and filled into cellulose casings to prepare even size meat models. Meat models were smoking overnight using smoke oven (OHMICHI Co. Ltd. Japan). Then meat models were cooked 1.5 hr at 72°C and kept under running tap water for 15–20 min for cool down.

2.5 | Testing the antioxidant efficacy of black and green tea extracts

As showed in Table 1 different concentrations of GTE and BTE (0.05%, 0.10%, 0.20%, and 0.30%) and 0.10% butylated hydroxytoluene (BHT), a synthetic antioxidant were added to meat models to test the antioxidant efficacies of both black tea extract (BTE) and green tea extract (GTE). Percentages of added tea extracts and BHT were calculated based on the total amount of product. Ice flakes quantity was replaced by GTE, BTE, and BHT during manufacturing of sausages. Five replications were performed and measurements were made in duplicate.

2.6 | Determination of pH

The measurement of pH was carried out on 10 g of homogenized sample in distilled water (1/10 sample/water). The pH value of the sample was determined using digital pH meter (HM-5S; TOA Electric Industrial Co. Ltd., Tokyo, Japan).

2.7 | Determination of 2-thiobarbituric acid reactive substances (TBARS)

Samples were analyzed for TBARS on days 1, 3, and 5 during storage at 37°C, according to the method of Siu and Draper (1978) with modifications. Two grams of each sample was weighed in a centrifuge tube to which 5 ml of a 10% (wt/vol) solution of tricoloroacetic acid (TCA) was added and vortexed (Fisher Vortex Genie 2; Fisher Scientific, Ontario, Canada) at high speed for 2 min. An aqueous solution (0.02 M) of 2-thiobarbituric (5 ml) was then added to each centrifuge tube, followed by further vortexing for 30 s. The samples were subsequently centrifuged at 3,000 x 10 g for 10 min and the supernatants were filtered through a Whatman No. 3 filter paper. Filtrates were heated in a boiling water bath for 45 min, cooled to room temperature in ice, and the absorbance of the resulting pigment was read at 532 nm using a UV spectrophotometer (D-17, Shimadzu, Japan). A standard curve was prepared using 1,1,3,3-tetramethoxypropane as a precursor of the malondialdehyde (MDA). The TBARS values were then calculated using the standard curve and expressed milligrams malondialdehyde equivalents per kilogram sample.

2.8 | Preparation of pork sausages for subjective and objective quality measurements

Pork sausages prepared for subjective and objective quality measurements were also formulated using the aforementioned procedure in Section 2.4 "*Preparation of meat model*." However, before grinding the meat mixers the following ingredients were added: 0.5% sugar, 0.6% pepper, 0.1% sage, 0.1% nutmeg, 0.1% garlic powder, 1% sodium ascorbate, and 0.1% sodium poly-phosphate N2 (Takeda Pharmaceutical Company Limited, Japan) composed of 75% sodium polyphosphate, 20% sodium pyrophosphate, and 5% sodium acid pyrophosphate.

Sausage samples added with 0.05% and 0.30% BTE and 0.05% GTE were compared with a control in sensory evolution, instrumental color evaluation, water holding capacity (WHC), and microbial analysis. After stuffing and cooking, all the samples were stored at

TABLE 1 Formulations of different concentrations of black tea extracts (BTE), green tea extracts (GTE), 0.10 BHT, and control meat models used in the study

Treatment	Lean %	Lard %	NaCl %	Ice %	BTE/GHT/BHT %
BTE 0.05%	58	20	2	19.95	0.05
BTE 0.10%	58	20	2	19.90	0.10
BTE 0.20%	58	20	2	19.80	0.20
BTE 0.30%	58	20	2	19.70	0.30
GTE 0.05%	58	20	2	19.95	0.05
GTE 0.10%	58	20	2	10.90	0.10
GTE 0.20%	58	20	2	19.80	0.20
GTE 0.30%	58	20	2	19.70	0.30
BHT 0.10%	58	20	2	19.90	0.10
Control	58	20	2	20.00	ND

Abbreviations: BTE, Black Tea Extract; GTE, Green Tea Extract; BHT, Butylated hydroxytoluene; ND, Not Added.

4°C, chilled overnight and the next day sensory evaluation was carried out. Instrumental color evaluation, WHC and microbial analysis were carried out on the 1st, 3rd, and 5th day of storage at 37°C.

2.9 | Subjective quality measurement of pork sausages

All the samples were evaluated using randomly selected 32 untrained (in house) panelists. Thirty gram of sausage samples from each batch were served to each panelist 2 min after frying. Drinking water in the room temperature and unsalted crackers were provided to clean the palate between the samples. A hedonic test was carried out to select the most consumer preferred sausage among tested four sausage types. Different sensory attributes, such as color, odor, texture, juiciness, taste, and overall acceptability was determined using five-point Hedonic scale.

2.10 | Objective quality measurements of pork sausages

2.10.1 | Instrumental color evaluation

Effect of the BTE and GTE on color properties (L^*, a^*, and b^*) of cooked pork sausages was evaluated by Minolta CM-2600d spectrophotometer (Minolta, Japan) throughout the 5 days storage period. The white standard was a piece of tile of known reflectance; the light source D65 and the standard observer angle 10° were used.

2.10.2 | Water Holding Capacity

Two grams of homogenized sausage samples were wrapped and transferred into the centrifuge tubes. Samples were centrifuge at 2600 × g for 4 min (MF6. NO W 70696 Hitachi, Japan). Finally samples were oven-dried at 70°C for overnight and WHC was calculated (AOAC, 1995).

2.10.3 | Microbial analysis

Frozen samples obtained during the storage period (1st, 3rd, and 5th day) were thawed to room temperature (28°C) and 10 g of each sample was homogenized with 90 ml buffered peptone and was properly blended. One milliliter dilutions were inoculated onto TPC petrifilm (PetrifilmR 3 M) to obtain Total Plate Count and incubated at 30°C for 48 hr. Furthermore, 1 ml dilutions were inoculated on to E. *coli* petrifilm (3 M™ Petrifilm E coli/Coliform count plates) and Baired Parker medium (Oxoid, UK) to obtain E. *coli* and S. *aureus* count, respectively, at 37°C for 24 hr.

2.11 | Statistical analysis

Objective measurements were taken with five replicates. The experimental design was Complete Randomized Design (CRD). Data were analyzed using SAS software package (SAS Institute, Cary, NC, USA). Means were compared using Duncan's Multiple Range Test. Experimental design for sensory analyze was CRD and one-way analyze of varies (Hedonic test) was performed. Data were analyzed using MINITAB software package. Differences at $p < 0.05$ were considered significant.

3 | RESULTS AND DISCUSSION

3.1 | Total Polyphenol content

The total polyphenol content of black tea before extraction (BBE) was 19.01% and after extraction (BAE) 30.01%. The total polyphenol content was 35.89% for green tea before extraction (GBE), which increased to 42.41% after extraction (GAE). Thus, the GAE total polyphenol content was significantly higher ($p < 0.05$) than in the BBE, BAE, and GBE samples (data not shown). Green tea extracts are well known for their high polyphenolic content (Pateiro et al., 2014). Rasouli Ghahroudi, Mizani, Rezaei, and Bameni Moghadam (2017) have shown that total phenolic content of black tea is around 207 ± 17 mg GAE g^{-1} dry weight of tea leaves and that it could be used as a source of antioxidant compounds in food products. Further, the anti-obesity character of tea is mainly ascribed to polyphenols, which could inhibit the activity of the enzymes related to the diet metabolism such as alpha amylase, alpha glycosidase, and lipase (Zhao et al., 2017).

3.2 | Antioxidant activity of tea leaves and tea extractions

According to the DPPH assay, green tea showed significantly higher ($p < 0.05$) antioxidant activity compared to black tea both before and after extraction (Figure 1a,b). The higher activity might be due to the corresponding higher polyphenol content in green tea compared to black tea. Karakaya, EI, and Taş (2001) found that the total phenol content and the antioxidant capacity of foods are significantly correlated.

3.3 | pH value

A significantly higher pH for the 0.3% GTE incorporated sausage sample compared to other treatments on the third day ($p < 0.05$) was observed. However, no difference was found between the GTE and BTE incorporated sausage samples on the fifth day of storage. Further, values for pH were reduced throughout the storage period (data not shown). Nevertheless, statistical analyses indicated that the addition of tea extracts lowers pH values ($p < 0.001$) in pork patties (Lorenzo, Sineiro, Amado, & Franco, 2014). Martínez et al. (2006) also observed the reduction of the pH value during the storage period of fresh pork sausage treated with green tea powder and pu-erh tea infusion. Low pH value is a positive character of sausages production, because microorganism growth is reduced in low pH values (Oseterlie & Lerfall, 2005), thus the shelf life of such products would be increased.

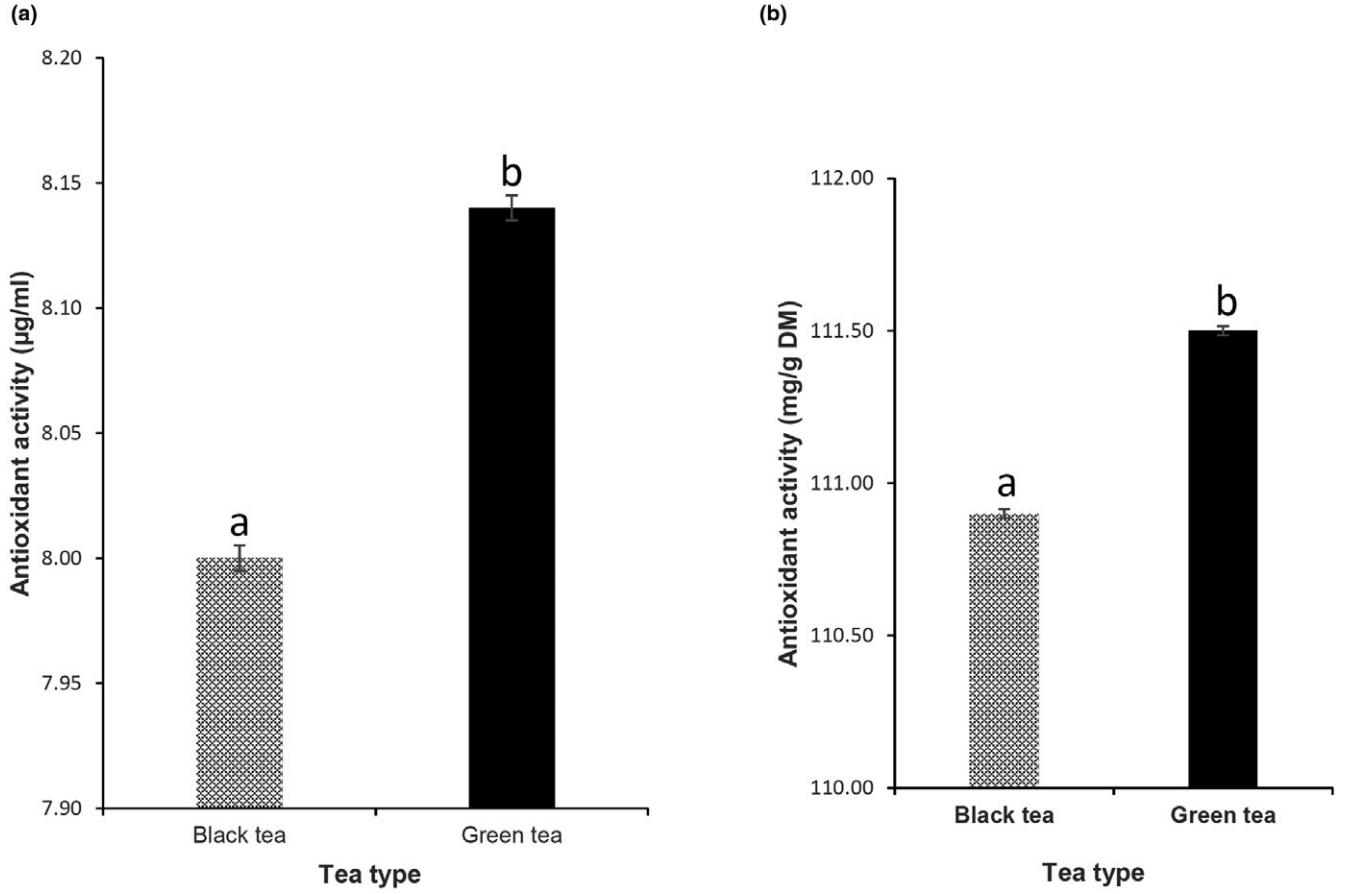

FIGURE 1 (a) Antioxidant activity of black and green tea before extraction (Trolox equivalence-µg/ml) and Figure 1 (b) Antioxidant activity of black and green tea after extraction (Trolox equivalence-mg/g DM) determined by DPPH assay. a, b-significantly difference at $p < 0.05$

3.4 | Thiobarbituric acid reactive substances value of pork sausages

The effect of different concentrations of BTE, GTE, 0.1% BHT and the control on TBARS values in cooked pork sausages during the 5-day storage at 37°C is shown in Table 2. According to Table 2, all BTE samples with different concentrations showed significantly lower ($p < 0.05$) TBARS compared to the 0.1% BHT added sample on the first and third day. In contrast, all GTE samples, compared to 0.1% BHT added samples, demonstrated significantly lower ($p < 0.05$) TBARS values on the third and fifth day of storage. TBARS values at the fifth day storage period, indicated that 0.05% BTE would be sufficient to inhibit the generation of malondialdehyde, as same as 0.1% BHT, in cooked pork sausages. Furthermore, the TBARS values for the controlled sample were significantly higher ($p < 0.05$) compared to all other samples throughout the storage period. Lipid oxidation reduction with BTE and GTE extracts in cooked sausages could be attributed to the presence of polyphenols, rich in catechins and theaflavins and thearubigins in green and black tea brews, respectively (Modder & Amarakoon, 2002). In addition, this was in line with

TABLE 2 The effect of different concentrations of BTE, GTE extracts, and 0.1% BHT on TBARS values (Malondialdehyde mg/kg) in uncured cooked pork sausages stored at 37°C

	Storage period		
Treatments	Day 1	Day 3	Day 5
BTE 0.05%	1.01 ± 0.16^{f}	1.72 ± 0.01^{c}	2.29 ± 0.01^{b}
BTE 0.1%	0.99 ± 0.01^{f}	1.51 ± 0.03^{d}	1.71 ± 0.04^{c}
BTE 0.2%	0.89 ± 0.02^{g}	1.21 ± 0.08^{gf}	1.64 ± 0.01^{cd}
BTE 0.3%	0.82 ± 0.08^{h}	1.22 ± 0.03^{efg}	1.60 ± 0.01^{de}
GTE 0.05%	1.42 ± 0.04^{b}	1.30 ± 0.01^{ef}	1.61 ± 0.08^{de}
GTE 0.1%	1.36 ± 0.12^{c}	1.51 ± 0.06^{d}	1.60 ± 0.02^{de}
GTE 0.2%	1.22 ± 0.02^{e}	1.10 ± 0.12^{g}	1.62 ± 0.04^{cd}
GTE 0.3%	1.34 ± 0.01^{c}	1.39 ± 0.04^{de}	1.50 ± 0.01^{ef}
BHT 0.1%	1.28 ± 0.15^{d}	1.99 ± 0.02^{b}	2.31 ± 0.09^{b}
Control	1.88 ± 003^{a}	3.48 ± 0.01^{a}	4.56 ± 0.01^{a}

Note. All values are mean ± standard deviation of three replicates. Means in the same column with different superscripts differ significantly. $p < 0.05$.

the findings of Bozkurt (2006), who reported significantly higher antioxidant activity in green tea extract incorporated Turkish dry-fermented sausages (Sucuk) compared to the 300 ppm BHT added sausages.

According to TBARS values, BTE 0.05% and 0.30% as well as GTE 0.05% concentrations were selected for further analysis. Among the GTE concentrations, the lowest concentration was selected because all the tested GTE concentrations showed a significantly higher capacity to reduce TBARS values compare to 0.1% BHT on day 5 storage. Lorenzo, González-Rodríguez, Sánchez, Amado, and Franco (2013) reported that the addition of antioxidants decreased ($p < 0.001$) oxidation as determined by TBARS, with greater reductions in sausages treated with natural antioxidants than with BHT.

3.5 | Sensory evaluation

In the sensory evaluation, pork sausage samples added with 0.05% and 0.30% BTE, 0.05% GTE, and control without tea extracts were compared (Figure 2). Data did not reveal any significant differences ($p < 0.05$) in color, odor, texture, juiciness, taste, or overall acceptability among the evaluated samples. However, consumer preference for color, texture, and overall acceptability were highest in the 0.30% BTE samples. Jo et al., (2003) also observed that there were no significant differences ($p < 0.05$) in odor, taste, and tenderness of cooked pork patties when added with freeze-dried green tea extracts. However, the color acceptability for the 0.30% BTE incorporated sausage sample might be due to the effect of thearubigins and theaflavin content. The fermentation of black tea during the manufacturing process formed thearubigins (~35%) and theaflavin (~0.2%) and which may have determined the color of tea liquor (Ananthacumarrasswamy & Singh, 2002).

3.6 | Instrumental color evaluation, WHC, and microbial analysis

According to Table 3, 0.05% and 0.30% BTE incorporated pork sausages showed significantly higher ($p < 0.05$) L^* value (lightness) throughout the storage period compared to the control sample. The

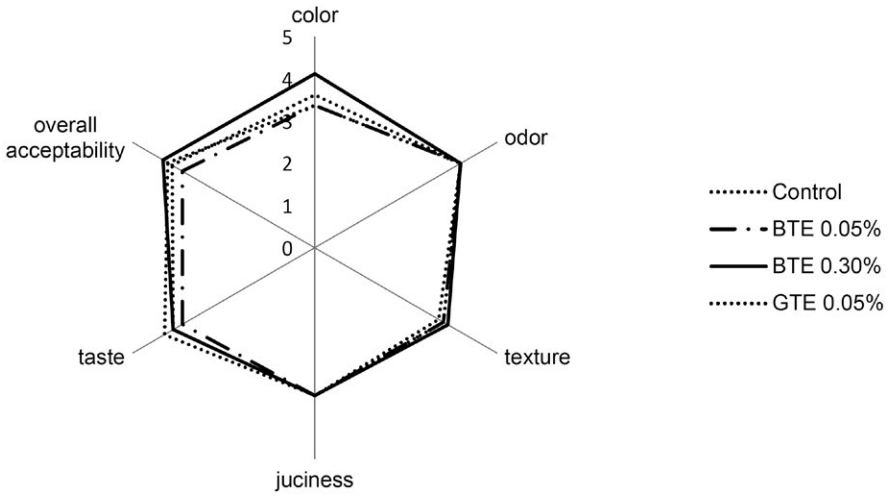

FIGURE 2 Spider web analysis of the sensory characteristic of uncooked pork sausages formulated with different concentrations of black tea extract (BTE), 0.05% green tea extract (GTE), and control (without BTE or GTE)

TABLE 3 Instrumental color evaluation (CIE lab L^*, a^*, and b^*,) of uncured pork sausages

Treatment	Days of storage	L^*	a^*	b^*
0.05% GTE	1	38.27 ± 0.90^{cd}	9.10 ± 0.69^{a}	11.37 ± 0.87^{b}
	3	37.03 ± 0.55^{ef}	6.37 ± 0.90^{g}	9.73 ± 0.98^{d}
	5	35.10 ± 0.86^{g}	5.83 ± 0.68^{h}	9.77 ± 0.74^{d}
0.05% BTE	1	38.30 ± 0.81^{cd}	7.80 ± 0.77^{c}	11.03 ± 0.89^{bc}
	3	39.20 ± 0.94^{c}	6.57 ± 0.82^{gf}	9.67 ± 0.83^{d}
	5	41.37 ± 0.78^{b}	6.33 ± 0.89^{g}	9.97 ± 0.58^{d}
0.3% BTE	1	43.00 ± 0.98^{a}	8.03 ± 0.65^{bc}	9.97 ± 0.62^{d}
	3	42.50 ± 0.67^{a}	7.30 ± 0.87^{d}	9.93 ± 0.98^{d}
	5	41.37 ± 0.92^{b}	7.10 ± 0.95^{de}	9.77 ± 0.75^{d}
Control	1	37.87 ± 0.53^{de}	8.2 ± 0.91^{b}	11.83 ± 0.49^{a}
	3	36.40 ± 0.85^{f}	6.83 ± 0.82^{ef}	9.77 ± 0.58^{d}
	5	33.70 ± 0.76^{h}	6.87 ± 0.96^{ef}	10.80 ± 0.64^{c}

Note. All values are mean ± standard deviation of three replicates. Means in the same column with different superscripts differ significantly. $p < 0.05$.

lowest L^* value was shown in the control sample on the fifth of storage and the highest in the 0.30% BTE incorporated sausage sample. However there was no any significant difference for redness (a^* values) between 0.30% BTE incorporated sausages and the control sample on the first and fifth day of storage. Regarding b^* values (yellowness), there was a significant different between the control and all other treatments on the fifth day of storage. The significantly higher ($p < 0.05$) a^* values for 0.30% BTE may be due to the 30%–60% of solids found in a typical black tea infusion. In line with these findings, Martinez et al. (2006) also observed that sausage formulated with pu-erh tea had significantly higher initial a^* value. However, Lorenzo et al., 2014, reported that pork patties treated with tea extracts were lighter and less red in color than control patties.

In the present study, sausages incorporated with 0.05%, 0.30% of BTE, and 0.05% of GTE did not show any significant differences ($p < 0.05$) in WHC compared with the control sample during the 5-day storage period. Similar results have been obtained by Gai, Gasco, Ortoffi, Gonzáles-Rodríguez, and Parisi (2014) reporting that the addition of green tea extract to tench fillets did not significantly change WHC compared to a control. According to the data on microbial analysis, *E. coli* were absent in all treatments and *S. aureus* were less than 10^2 CFU per gram. Total plate counts of sausages formulated with BTE, GTE, and the control were not significantly different during the 5-day storage period. This may be due to the strict hygienic practices followed during the production process at the Meat Processing Laboratory, at the Department of Animal Science, University of Peradeniya, Sri Lanka.

4 | CONCLUSION

According to the results of the present study, the ability of 0.05% of BTE to suppress TBARS values in uncooked pork sausages is in par with the effect of 0.10% BHT, a commonly used synthetic antioxidant. Furthermore, additions of 0.30% BTE and 0.05% GTE to uncooked pork sausages suppress the TBARS values better than 0.10% BHT. Both BTE (0.05% and 0.30%) and GTE suppress TBARS values in uncured pork sausages without altering the sensory attributes such as color, odor, taste, texture, and overall acceptability. Thus, 0.05% of black tea extract as well as 0.05% green tea extracts can be incorporated to meat systems as natural antioxidants without any adverse effects on sensory attributes.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

ORCID

Barana C. Jayawardana https://orcid.org/0000-0002-8563-2378

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